

## Study of GdCo/Si/Co/Si Multilayers by Polarized Neutron Reflectivity

To cite this article: R López Antón *et al* 2011 *J. Phys.: Conf. Ser.* **325** 012018

View the [article online](#) for updates and enhancements.

### Related content

- [Structural and magnetic properties of Ru/Ni multilayers](#)  
K Mergia, A Tomou, I Panagiotopoulos et al.
- [Magnetic moment distribution in non-stoichiometric Ni-Mn-Ga ferromagnetic shape memory alloys](#)  
P Lázpita, J M Barandiarán, J Feuchtwanger et al.
- [Structural and magnetic characterization of \[Co<sub>2</sub>MnGe/MgO\]<sub>n</sub> and \[Co<sub>2</sub>MnGe/Al<sub>2</sub>O<sub>3</sub>\]<sub>n</sub> multilayers by polarized neutron reflectivity](#)  
M Vadalá, A Lamperti, M Wolff et al.



**IOP | ebooks™**

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

## Study of GdCo/Si/Co/Si Multilayers by Polarized Neutron Reflectivity

**R. López Antón<sup>1</sup>, A.V. Svalov<sup>2,3</sup>, J.M. Barandiarán<sup>2</sup>, T.R. Charlton<sup>4</sup>, M. Krzystyniak<sup>5</sup> and G.V. Kurlyanskaya<sup>2</sup>**

<sup>1</sup> Departamento de Física Aplicada, Facultad de Químicas, IRICA, Universidad de Castilla-La Mancha, 13071 Ciudad Real, Spain

<sup>2</sup> Departamento de Electricidad y Electrónica, Facultad de Ciencia y Tecnología, Universidad del País Vasco, P.O. Box 644, Bilbao 48080, Spain

<sup>3</sup> Institute of Physics and Applied Mathematics, Ural State University, 620083, Ekaterinburg, Russia

<sup>4</sup> ISIS, Rutherford Appleton Laboratory, STFC, Chilton, Didcot OX110QX, UK

<sup>5</sup> Oxford e-Research Centre, University of Oxford, Oxford, OX1 3QG United Kingdom

E-mail: Ricardo.lopez@uclm.es

**Abstract.** In order to better understand the interesting magnetic behaviour found in the Rare Earth-transition metal/(spacer)/transition metal multilayers, a multilayer of Co/[Si/Gd<sub>0.36</sub>Co<sub>0.64</sub>/Si/Co]<sub>4</sub>/glass was studied by SQUID magnetic measurements and polarized neutron reflectivity. A model for the magnetic profile of the sample was proposed, which fitted well the polarized neutron reflectivity measurements at different magnetic states: ferrimagnetic/antiparallel state, under an applied field of 55 Oe, canted states (315 and 675 Oe) and saturation state (1700 Oe). It was found that even at the expected collinear states (ferrimagnet and saturation states), the magnetization was not totally collinear and there was a small component of the magnetization perpendicular to the applied field

### 1. Introduction

Magnetic rare earth/transition metal (RE/TM) multilayers have been a subject of considerable interest in recent years. Their specific features are the antiferromagnetic exchange coupling between RE and TM layers, and a wide variety of magnetic configurations created by temperature and field. The magnetic state of the multilayers corresponds to aligned and twisted phases at low fields and high fields respectively [1]. For practical applications, replacing the RE element by a RE-TM alloy is a clear advantage, with higher Curie point  $T_c$ , far above RT [2]. On the other hand, RE/TM structures containing non-magnetic spacers between magnetic layers have not been studied in as much detail although interesting peculiarities have been found for such systems, as, e.g., decrease of the strength of the coupling between magnetic layers with the increase of spacer thickness [3-4], spin-glass-like behaviour of the magnetization in low fields [5].

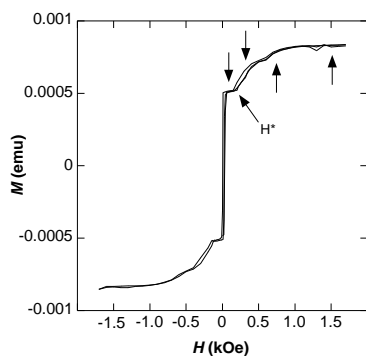
Polarized Neutron Reflectivity, PNR, is a powerful depth-resolved technique to determine the magnetization profiles of magnetic multilayers. However, in the case of RE/TM and Re-TM/TM multilayers, there are several works studying Fe/Gd multilayers [6-8], but only a few works by J.A. Gonzalez et al [9] on GdCo/Co multilayers exist, focusing on the creation of an interfacial region in Gd<sub>0.63</sub>Co<sub>0.37</sub>/Co not existing in the Gd<sub>0.40</sub>Co<sub>0.60</sub> one. In this work we study a sample with a non-magnetic spacer between the GdCo and Co layers so as to determine its magnetic profile in the collinear and twisted states.

## 2. Experimental

The samples were deposited onto glass substrates at room temperature (RT) using three-target RF sputtering. A mosaic target of composition Gd<sub>0.36</sub>Co<sub>0.64</sub> was used for preparation of the Gd–Co layer. The background pressure was 10<sup>-7</sup> mbar and the deposition was performed in Ar atmosphere with a partial pressure of 2·10<sup>-4</sup> mbar. The studied multilayer is glass(substrate)/[Co(7)/Si(0.8)/GdCo(12)/Si(0.8)]4/Co(7) (thickness in nm). A magnetic field of 100 Oe was applied during deposition in order to induce magnetic anisotropy in-plane of the film.

The magnetic hysteresis loops were measured using a SQUID magnetometer (Quantum Design MPMS®) at RT with applied fields of up to 70 kOe. The surface root-mean-square roughness of the sample was measured by atomic force microscopy and its value, fairly low indicating the quality of the sample, is 1 ± 0.2 nm.

The PNR measurements were obtained at the CRISP reflectometer (ISIS spallation source, RAL-STFC) at RT and different magnetic fields. The neutrons were polarized by a supermirror in a direction traverse to the beam and parallel to the magnetic field axis and to the film surface. The spin-dependent reflectivities ( $R^+$ ,  $R^-$ ) were collected in this specular condition as a function of neutron wavelength for a corresponding momentum transfer ( $q_z$ ) in the range 0.008 Å<sup>-1</sup> to 0.12 Å<sup>-1</sup>. The symbols + and – refer to the polarisation of incident neutrons relative to the applied field; parallel (+) and antiparallel (–). In a few cases we also carried out polarisation analysis (P.A.) of the reflected beam, that is, measured  $R^{++}$ ,  $R^{+-}$ ,  $R^{-+}$ , and  $R^{--}$ . The first symbol refers to the state of incident neutrons whereas the second refers to the state of reflected neutrons. The reflectivity values were normalized to total reflection. The fit of the PNR data was performed using POLLY software (developed by S. Langridge et al. (ISIS, RAL-STFC) based on [10]).



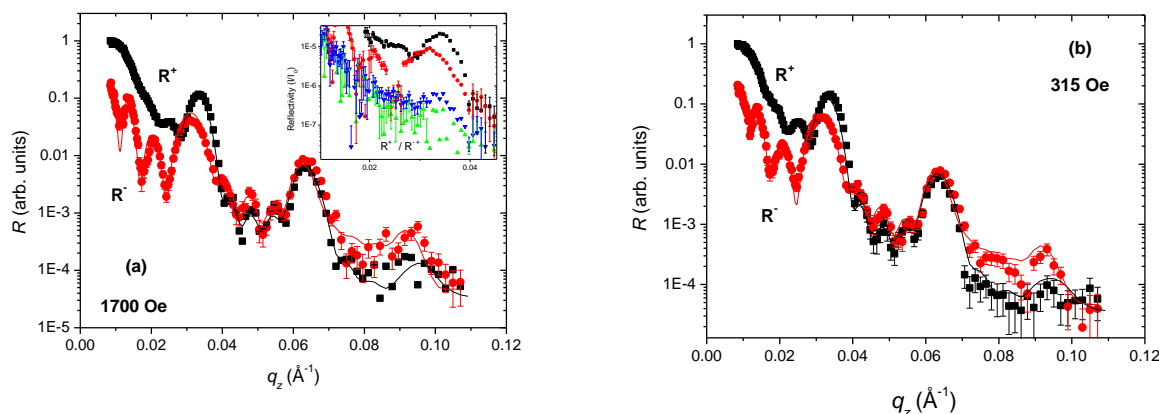
**Figure 1.** Magnetic hysteresis loop measured at RT. The vertical arrows indicate the points where the PNR measurements were taken.

## 3. Results and discussion

Because of the negative Gd–Co and positive Co–Co exchange interaction near the interface, the total magnetic moments of Gd–Co and Co layers are antiparallel (Figure 1), i.e., these multilayers form a macroscopic ferrimagnet. In low fields, the magnetizations of Co and Gd–Co layers are anti-aligned along the direction of the applied field. If the field is higher than the critical field  $H^*$  the moments of both the Co and Gd–Co layers deviate from the field direction (Fig. 1), which leads to the appearance of different slopes on the hysteresis loops. Hence, at the critical field  $H^*$  SQUID hysteresis curves show a “kink”.  $H^*$  is considered to give an estimate of the exchange coupling strength. Figure 1

shows the hysteresis loop, where the commented “kink” can be observed at about 100 Oe (indicated by  $H^*$  in the graph). At  $H^*$  the twisted state begins, and in fact two regions with different slope (and likely different canted structure) are found thereafter [11]. Measurements with fields up to 7 T do not show any further feature. In Figure 1 the points which have been studied by PNR are indicated by vertical arrows, corresponding to the ferromagnetic state (55 Oe, anti-parallel moments), canted states (315 Oe and 675 Oe, in the 2 regions with different slopes) and saturation state (1700 Oe, parallel moments).

In Figure 2 are shown two of the PNR spectra of the sample, with their corresponding fits. In the inset of Figure 2 (a) is shown a detail of P.A. at that field and around the Bragg peak, where a distinctive spin-flip reflectivity ( $R^+/R^-$ ) is found. This pinpoints that the magnetization is not completely parallel or antiparallel to the applied field [7], in contrast to what was previously anticipated. Hence, in the fit of the other PNR data, we also include the angle  $\theta$  of the magnetization as one of the fitting parameters.



**Figure 2.** Experimental (points) and fitted (lines) PNR spectra at RT measured under an applied field of 1700 Oe (a) and 315 Oe (b). Inset in (a): detail of P.A. measurement around the first Bragg peak, evidencing the existence of spin-flip.

The magnetization profile of the sample was analyzed by fitting the experimental reflectivities, taking into account the magnetic measurements. In that sense, the possible fitting parameters (for each layer) are the scattering length  $b$ , the nuclear density  $N$ , the magnetic moment, the angle of the magnetization (in the plane of the sample), the thickness, the roughness and the absorption. Initially we used the nominal thickness of the layers and determined  $b$  and  $N$  from tabulated values. We also added a layer of Co oxide on top of the sample. Absorption of neutrons is expected only in the GdCo and glass layers (due to Gd and B respectively). The preliminary fits matched the data fairly well around the Bragg peaks, showing that the nominal thickness values were quite close to the actual ones. For simplicity's sake, and taking into account what was found in the P.A. data, we fitted the data by fixing the densities and magnetization obtained in the preliminary fits of the extremes of the series of measurements (i.e., at 55 and 1700 Oe), and then allowed the angle of the magnetization of the layers to change. The results are shown in Table 1.

The fit results show a small difference in the magnetization and density from bulk values and the measured moment of the film by the SQUID. This is typical for thin film systems and the values are within experimental error. The evolution of the angles with the applied field agrees well with the proposed magnetic model in similar multilayers [11], with the main difference of the non-collinear state at low and high fields. In the case of the measurement at 55 Oe, the angle of the GdCo layer magnetization is 126 degrees, far from the antiparallel case. This is most likely due to the fact that

magnetic moment of each layer behaves not entirely like one. Hence, a more complicated magnetic structure inside the GdCo layer is required. Therefore a more complete study using PNR with P.A. so as to determine the full magnetic structure would be beneficial and we intend to do it in the future.

**Table 1.** Main results obtained from the fits of the PNR spectra for the magnetic layers.

Layer	Thickness (nm)	Moment ( $\mu_B$ )	$\theta$ (deg)			
			55 Oe	315 Oe	675 Oe	1700 Oe
Co	6.0	1.55	7	16	16	11
GdCo <sup>a</sup>	12.0	0.55	126	70	33	8
Co <sup>a</sup>	6.5	1.55	4	17	16	4

<sup>a</sup> Repeated bilayer (4 times)

#### 4. Conclusions

A multilayer of Co/[Si/Gd<sub>0.36</sub>Co<sub>0.64</sub>/Si/Co]<sub>4</sub>/glass was studied by SQUID magnetic measurements and polarized neutron reflectivity. A simple model for the magnetic profile of the sample was proposed and this model fits well the polarized neutron reflectivity measurements at the different magnetic states. The fit results show a small difference in the magnetization and density from bulk values and the measured moment of the film by the SQUID, but these were within experimental error. Finally, it was found that even at the magnetic fields where collinear states (ferrimagnet and saturation states) are expected, the magnetization was not totally collinear and there was a non negligible component of the magnetization perpendicular to the applied field.

#### Acknowledgments

The authors would like to thank C. Kinane (ISIS, RAL-STFC) and I. Orue (Sgiker, UPV/EHU) for their kind help with PNR and magnetic measurements respectively. This work was funded by Spanish MEC (project MAT2008-06542-C04\_02) and was supported in part by RFBR (Grant No. 11-02-00288-a).

#### References

- [1] Camley R E and Tilley D R 1988 *Phys. Rev. B* **37** 3413.
- [2] Niemeyer A, Reiss G and Brückl H 2006 *Appl. Phys. Lett.* **88** 182503
- [3] Takanashi K, Fujimori H, Kurokawa H 1993 *J. Magn. Mater.* **126** 242
- [4] Svalov A V, Fernandez A, Vas'kovskiy V O, Kurlyandskaya G V, Barandiarán J M, Lopez Anton R, Tejedor M 2006 *Journal of Alloys and Compounds* **419** 25
- [5] Patrin G S, Vas'kovskii V O, Velikanov D A, Svalov A V and Panova M A 2003 *Phys. Lett. A* **309** 155
- [6] Dufour C, Cherifi K, Marchal G, Mangin Ph and Hennion M 1993 *Phys. Rev. B* **47** 14572
- [7] McGrath O F K, Ryzhanova N, Lacroix C, Givord D, Fermon C, Miramond C, Saux G, Young S and Vedyayev A 1996 *Phys. Rev. B* **54** 6088
- [8] Kravtsov E, Haskel D, te Velthuis S G E, Jiang J S and Kirby B J 2009 *Phys. Rev. B* **79** 134438
- [9] Colino J, Gonzalez J A, Andrés J P, López de la Torre M A and Riveiro J M 2002 *Appl. Phys. A* **74** S1573
- González J A, Colino, Andrés J P, López de la Torre M A and Riveiro J M 2004 *Physica B* **345** 181
- [10] Blundell S J and Bland J A C 1992 *Phys. Rev. B* **46** 3391
- [11] Svalov A V, Fernández A, Vas'kovskiy V O, Lopez Anton R, Barandiarán J M, Tejedor M, Kurlyandskaya G V 2007 *Physica B* **396** 113